STOCK-AND-FLOW THINKING IN DECISION MAKING.

TOWARDS SYSTEMIC PROCEDURE OF PROBLEM SOLVING.

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Abstrakt

The article presents fundamental rules of the systemic thinking in decision making and it proposes a unified problem solving procedure. The Partitioning Method is presented and it is shown how that method can be used in discovering system structure or problems. The problem structure is a critical factor in solving them. Special attention is paid to the variables described as Stock-and-Flow which absorbs the problems' dynamics and deteremine its feedback structure. The analysis is presented as part of the Dynamic Decision Making theory.

Introduction

The work that steers the fate of societies and their economic and governmental organizations is largely the task of making decisions and solving problems. It is the work of seeking problems that require attention, setting their goals and criteria, designing suitable solutions, and choosing from available solution alternatives. The first three activities - finding problems, setting criteria, and designing solution alternatives are commonly called problem solving; the last, evaluation and choice, is usually called decision making.

The abilities and skills that determine the quality of decisions and appropriateness of problem solutions depend not only on human minds, but they also are supported by physical tools and machines (computers, in particular) and many mind-like constructs that we call decision models. In psychology, economics, statistics, operations research, political science, artificial intelligence, and other cognitive science, problem solving and decision making have gained considerable interest and space in science development.

Two research currents have been developed; the first one, of prescriptive nature, centers decision making knowledge around the concept of subjective expected utility, a mathematical model of choice making. Accordingly, most contemporary economics, statistics, and operations research recommendations set the decision theory either in a world of perfect utility-maximizing rationality in a world of certainty or in a world where decision makers can define the probability distributions of all relevant variables. This perspective deals only with decision making; it does not explain how problems are discovered, goals set, or solution alternatives developed. Empirical research works do not support the prescriptive approach. They show that human mind, while coping with high complexity and vast psychological space in which problem solving is carried out, shelters into limited rationality, where solutions quality satisfies more subjective criteria and psychological comfort than their optimum.

The other current, descriptive theory of problem solving and decision making is concerned with how people gain knowledge of problems and how they heuristically cope with the complexity of problems. When the goals themselves are complex and sometimes ill-

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defined and when the nature of problems must be transformed in the course of exploration, the recommendations of prescriptive theories fail. Those problems, sometimes called “ill-structured”, require different approach. The whole process of problem design characterizes by new emerging conceptions which provides constant feedback that enrich further work towards its solution.

With new modeling tools (e. g. Systems Dynamics, Learning Organization) it is just beginning to be possible to build environments that simulate this kind of flexible problem-solving process. Most management strategy and public policy problems are ill- structured. In this article we argue that external (tools) and internal (decision models, e. g. linear programming) assistance are of limited use unless we embed them into a broader problem solving methodology, called “stock-flow thinking” (SFT), hereafter.

Failures in problem solving and decision making.

For decades decision making and problem solving have been a pillar of interest for the theory and practice of the organization and management. Beginning with classic works by H. Simon (bounded rationality), through provocative seminal works by J. March, M. Cohen, and J. Olsen (Garbage Can Model), and more recent developments, a continuous effort has been made to understand the nature of decision making and problem solving. Unlike research works developed in past decades, recent interest seeks assistance in viewing these processes in the context of complexity and dynamic properties, where both these concepts are intimately interrelated. Complexity can take either non dynamic form (represented by the number of components constituting an entity, e. g. problem to be solved) or dynamic one; dynamic complexity is interpreted as the behavioral variability – problem ability to show behavior that changes over time. Certainly, the dynamics of the problem behavior stems from the number of its elements and relationships existing among them (Senge 1990: 72).

Two problems arise here. First – human mind is not suited to correctly perceive changes. Instead, we tend to see changes as a sequence of states the value of which make a change possible to detect. Rooted in educational system and teaching philosophy, our language has acquired stationary character and it has not developed towards change representation and interpretation. Language captures and elicits knowledge of problems in a specific, static way – problem description cannot be more precise than language used for doing this. It is often called “generative power of language” and it affects not only problem description but, first of all, problem perception.

All of us have been explicitly or implicitly trained in the Cartesian view of knowledge, and it has dominated Western science for centuries. Its essence is the belief that there is a clear separation between mind and body, between thinking and doing, between management and the employees. On top of that dogma there is the notion that knowledge is a substance which can be separated from any other substance. Thus, knowledge can be encapsulated and locked in many compartments with clear separation among them. Each capsule can be taught and it can be taught with almost no relation to other capsules. The theory of pedagogy, educational process, or corporate training is following this path and reducing learning to how we find a way to optimally pour knowledge into people’s heads with the recognition that there is already something alreadyin their heads. This “something” is frequently an obstacle to new substance; thus, in order to learn we first frequently must unlearn what we have learned earlier…

Humans live in two worlds – one is the world of events and processes and the other is the world of our perception and cognition operating as a map giving sense to events and processes. While telling stories we organize our cognitive and perceptual space creating our territory of action. Three questions arise here: 1) how do we do that, and 2) what is the context for mapping our perception, and eventually 3) what instruments can we use for “what we do in that context”.

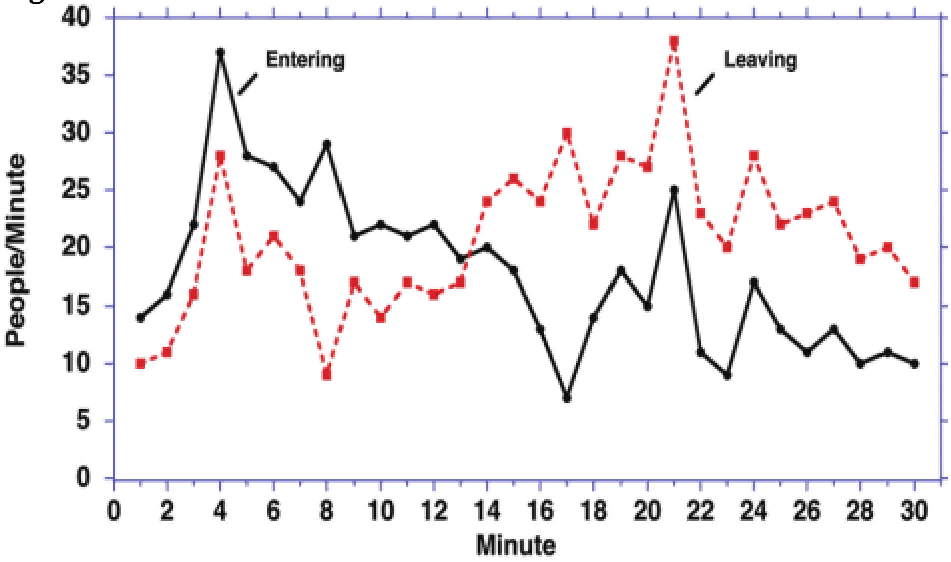
Kofman and Senge (1993) say that in our everyday sense of the world, we see reality as "out there" and ourselves as observers "in here." Our Western tradition compels us to "figure out" how nature works so that we can achieve what we want. But what if what shows up for us as "reality" is inseparable from our language and actions? Therefore, we use available language for mapping our territory where the map makes sense only when it depicts differences and conceptually distant phenomena. We think through differences and linking different concepts into a more coherent picture we understand our world. This is clearly related with knowledge representation and learning embedded into the contemporary current of knowledge management in corporations as well at schools. In both, new information incorporation and in coding and storing existing information we use the already existing maps of our cognitive territory, using language as a vehicle and a sense making tool. Such is the contents of the learning process. Individual perception and social context can be purposefully arranged and assisted by many methods and instruments.

In a rather anecdotic experiment we may ask for precisely telling the contents (notes) of the Beethoven's Fifth Symphony (using natural spoken language) or to present with tunes the contents of an inventory problem – each type of problem calls for an appropriate language.

Second – our language rooted cognitive limitations affect our understanding of dynamic phenomena. Well-known experiments (Cronin, Gonzalez 2007), Sterman 2000, Sterman 2010) ask students to answer simple questions about the number of customers in a store based on the following graph (see: Fig. 1).

The graph below shows number of people entering and leaving a store over a 30 minutes period.

Fig. 1. J. Sterman's Store Exercise



Source: Sterman 2010.

Questions, among others, were about when maximum number of people *enter* and *leave* the store and when maximum and minimum number of people *whereas in the store.* Most answers about entering and leaving customers were correct; very few, however, ascertained correctly the time of having the highest and the lowest number of customers in the store – originally it was 36% of correct answers15.

This simple experiment is very educational. It shows us a common difficulty in discerning change process from change results when the latter is not directly accessible but must be derived from gradual changes (which in turn are observable – customers entering and leaving store). In one experiment performed by the author the original experiment was followed by another one. Data were the same, yet the original graph was split into two - one presenting only number of customer entering the store and the other one showing the number of customers leaving the store (with an initial number of customers in the store). In these cases students did not have any problem answering questions – they correctly pointed to the end of a 30 minutes time as the time when either the number of customers was the highest (for customers entering) or the lowest (for leaving), respectively. The combination of both makes the exercise much more difficult and even highly trained in mathematics and sciences students do not perceive correctly dynamic properties of the store.

Correct interpretation of the store dynamics requires understanding of a “change language”. Change language makes a distinction between gradual changes and their accumulated results. In the experiment gradual changes are entering and leaving customers, their number in the store is an accumulated result. Correct answer (for original graph) is that the store has maximum number of customers at time=14, and at time=30 their number is the lowest. Whenever the number of entering customers is higher than the number of leaving customers, its total number is increasing; in the contrary situation (leaving>entering) the total number of customers is decreasing through the end of the whole period of time. Poor interpretation of the store dynamics cannot be attributed to an inability to interpret graphs, contextual knowledge, or cognitive capacity. It is more related with our limited (and promoted by our language) capability to discern gradual changes from their results.

As gradual changes and their results are common in systems of all types (Forrester 1961), we can expect that most decisions involving them will be incorrect. That is why this distinction has played a central role in many disciplines, ranging from management to epidemiology. The ability under interest is called “graphical integration” and it helps to determine how the accumulated quantity changes over time given certain rates of change flowing into and out of it. Gradual changes are called “rates” and they flow into or out of the resulting value called “stock”. Stocks cannot change without flows (rates).

Another shortcomings in problem solving comes from the feedback structures frequently underlying problems structure. In his insightful paper Sterman (1987) showed how managers in a simulated industrial production and distribution system ("Beer Distribution Game") seek to minimize total costs by managing their inventories appropriately under uncertain demand. Simple structure of the simulated environment contains multiple actors, feedbacks, nonlinearities, and time delays. The interaction of individual decision makers with the structure of the simulated firm produces aggregate dynamics which diverge systematically from optimal behavior. They generate large oscillations in the inventory getting away from the planned goal – inventory cost minimization. They clearly misperceive the feedback involved in the situation - they fail to control actions which have been initiated but not yet terminated; they also fail in understanding impact by other subjects participating in the game.

Repeated several times this experiment in the classroom (WSB – NLU) yields the highest score of 42% and 23% the lowest

They blame external factors for their poor performance when in fact the dynamics they experience are internally generated by their own actions. They misperceive feedback loops existing in the problem structure.

The dynamics of problem solving in theory

The complex and dynamic nature of problem solving and decision making has been extensively researched by recent development of the Dynamic Decision Theory. For our aims four issues raised by this current are important:

a) Dynamics – resulting from continuous changes within a problem constituting multiple loops through which a variable can influence itself or other variables over time. These feedback loops underlie major processes in systems - growth, fluctuation, and decay. They can be self-reinforcing (positive feedback loops), while those that are self-correcting are referred to as negative feedback loops. Concomitant with these feedback loops caused both by a decision maker's actions and by the interactions among the system variables, problem acquires new qualities – its internal dynamics.

b) Complexity - dynamic problems comprise parts that interact or interconnect in an intricate manner, making it difficult to understand or predict system behavior. As discussed earlier, among factors that contribute to problem complexity we have the number of components, the number of relationships among the components, and the types of relationships among them. The latter determine the type of feedback existing in the problem, thus resulting in the problem dynamics.

c) Opaqueness - it refers to the "invisibility" of some aspects of the problem (Brehmer 1992). Although information about the problem may be available (i.e. observable), it is accessible only if the decision maker knows where to find it. Furthermore, the usefulness of the available information depends upon what the decision maker knows about its relationship to current goals.

d) Feedback - for controlling dynamic problems, decision makers must access information about

its state by monitoring feedback loops. Such monitoring does not search for the existing information but rather relies on mental simulation of the problem behavior. Decision maker's imagination, mental model of the problem, and testing problem structure with the use of available tools are instruments and ways of accessing that information. It is very common that feedback loops existing in the problem structure are interrelated and they collectively form the problem's "feedback structure". Further part of the article shows how we can use certain sequence of operations to learn about feedback structure. The problem's feedback structure encompasses and combines two previous concepts of the dynamics and complexity to emphasize the effect of feedback structures on a decision maker's ability to control dynamic problems.

Diehl and Sterman (1995) claim that three elements of the problem's feedback structure are particularly relevant. The first feature are side effects generated by feedback loops. A side effect is an unexpected result of an action that has been undertaken to produce some desired results. Side effects usually accompany desired effects and erroneously tend to be treated as mistakes produced by the decision maker's behavior. In reality, there are no side effects, there are just *effects*. When we take action, there are various effects. The effects we thought of in advance we call the main, or intended effects. The effects we didn't anticipate are these which through the feedback mechanism undercut our policy and the ones we claim to be side effects. Side effects are not a feature of reality but a sign that our understanding of the system is narrow and insufficient. Systems perspective in seeing problem structure does exclude such an "unplanned deficiency", claiming that side effects are natural consequences of any feedback structure. The third element is feedback delays. Time plays a specific role in the problem's feedback structure; any process or action takes a certain amount of time to complete, resulting in delays between the decision making time and the time at which information about the effect of the decision results is available.

Interpreting problem solving and decision making as dynamic phenomena, several conditions must be fulfilled. Brehmer (1992) stated that:

1. Dynamic decision making relies on stock-flow thinking.
2. Goal attainment requires a series of decisions, where the next decision can be understood only in context of the previous one; thus:
3. Decisions are not independent
4. Problem evolves over time as the consequence of itself and previous decisions
5. Most important part of psychological framework affecting problem solving is the capability to see patterns in problem structure. There are four general preconditions for controlling problem solving process:

- there must be a goal (goal condition),
- must be perceivable state of the system represented by problem (observability condition); this includes:
- access to flows causing changes in the system,
- access to information about results of these changes (stocks)
- there must be a possibility to affect the system (action condition),
- the problem must be a model of system (model condition),

Stocks and flows

In the last decades much effort has been put into understanding benefits and shortcomings of thinking patterns in problem solving. A long list of research works includes Bakken, Cavaleri&Sterman,Vennix, Doyle, Ossimitz, Roberts - just to mention a few. Unfortunately, these studies have not led to a major consensus regarding required decision maker's native thinking abilities and many important questions remain unanswered.

Studies belonging in systems sciences stress different concepts – capabilities deducing behavior patterns and circular cause–effect relations, revealing a system's structure, ''seeing wholes''. They all emphasize the importance of the ability to represent and assess the problem's dynamic complexity. Specific systems thinking skills include (in addition to more formal, "teachable" skills):

- understanding how the behavior of a system arises from the interaction of its components over time (dynamic complexity),
- discovering and representing feedback processes (both positive and negative),
- understanding observed patterns of problem behavior, their nonlinear nature in particular,
- identifying stock and flow relationships,
- recognizing time delays and understanding their impact upon a problem,
- constructing and challenging the boundaries of mental and formal models underlying problem solving.

All studies show that decision making performance deteriorates rapidly when even the slightest contents of dynamic complexity are introduced. Despite the usual explanation blaming human bounded rationality, there is a strong suggestion that the problem's dynamic complexity overwhelms our cognitive capabilities, basically because of our unpreparedness to discern among various and different types of variables forming a problem. The mismatch between cognitive capabilities and problem dynamics has frequently led to inappropriate scientific analysis, and even to the formulation of erroneous theories; as Joan Robinson wrote in 1982: ... "(economics) it is the science of confusing stocks with flows. It is this confusion that has kept the Quantity Theory of Money alive until today."

If we think of the variables in terms of what type of behavior they may present and analyze possible behavior of variables over time, there are only three patterns:

- variables with present states depending on their previous states; those variables show the accumulation or depletion of certain resources important for the problem. Those variables are called stock, state, or level variables: stock variables represent resources within a problem,
- variables that are responsible for the conversion of resources; stock variables change over time according to a certain transformation rules contained in another variable, linked with level variable; those variables are called flow or rate variables and they directly increase or deplete resources level in stock variables,
- variables that are neither stock nor flow variables; they usually intervene between stock and flows and convert internal or external influences into a language understandable for stock and flow variables, they are called conversion variables (converters).

The importance of distinguishing different types of variables is justified by different contribution of these variables to the problem structure and behavior. A link between structure and behavior is perhaps the most important paradigm of the Systems Dynamics (Senge 1990). Any problem has a structure and the problem behavior is not dominated by its variables alone but it depends on the relationships existing among them. The structure must then be analyzed as a whole paying special attention to feedback loops existing in the structure. Thus, not variables themselves but what occurs in and among variables determines problem behavior (symptoms) and possible solution of that problem. In other words, solving a problem implies our intervention in its structure, particularly in its feedback elements.

The distinction between stock and flow variables is crucial here. As Sterman wrote (2002, p. 193 and further), stock variables are accumulations and they characterize the state of the system and generate the information upon which decisions and actions are based. Stocks protect problems (systems) against sudden changes and provide them with memory.

Diagramming convention for stocks and flows was originated by Forrester (1961) who used a hydraulic metaphor - the flow of water into and out of reservoirs.

The stock and flow structure has a precise mathematical meaning. Stocks accumulate or integrate their flows with corresponding integral equation:

$$\text{Stock}(t) = \int(\text{Inflow} - \text{Outlow})(dt) + \text{Stock}(t-1)$$

where (t)=final time, (dt)=time interval, (t-1)=preceding time moment. The expression Stock(t-1) provides variables with “memory” guarantying that the stock variable does not “forget” its previous state. Stock variables change according to net flow into it; therefore, the net rate of change of any stock is its inflow less outflow, defining the differential equation:

$$d(\text{Stock})/dt = (\text{Inflow} - \text{Outflow})(t)$$

and, as a consequence, we can construct the corresponding stock and flow map from any system of integral or differential equations as well as from any stock and flow map we can generate the corresponding integral or differential equation system (such a natural conversion of human thinking and formal operations is unacceptable for mathsfearing people).

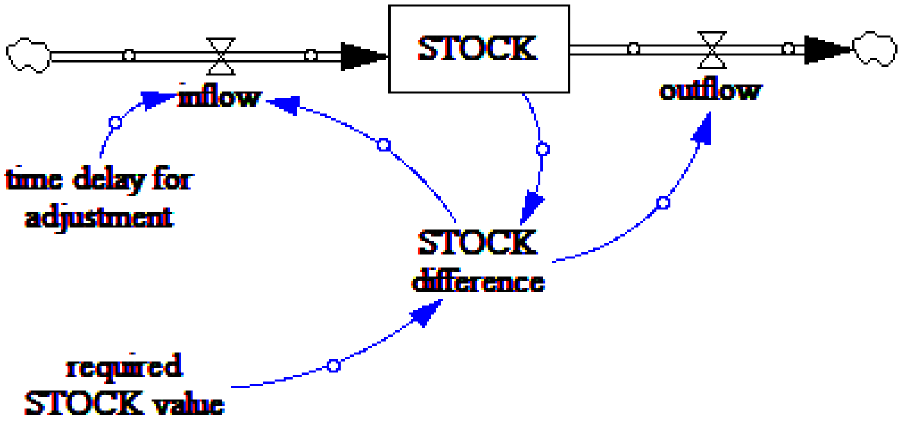
Stocks are critical in generating the dynamics of systems for the following reasons (Mass 1980):

- Stocks characterize the state of the system and provide the basis for actions. The evaluation of a problem solution must be based on the stocks' values. They do not have to be tangible; we can think of stock representing the accumulation of knowledge, experience, motivation, or perceived quality of a product,

- Stocks provide systems with inertia and memory; they accumulate past events and can only change through the net value of inflow and outflow. Keeping those values stocks provide continuity and links between previous states and present situation,
- Stocks are the source of delays – conversion of inflows into outflows produces time lag forming an important part of a problem dynamics,
- Stocks disconnect rates of flow and create disequilibrium in a problem; in static situation the total inflow to a stock equals its total outflow and the stock value is constant. Any solution is a disequilibrium introduced into a problem, thus flows decoupling is the sine qua non condition for problem solving.

Given the fundamental role of feedback loops in problem structuring, an important rule can be stated: e*very feedback loop in a system dynamics model must contain at least one stock.* Consequently, it is possible to propose a basic controlling component for any problem structure called Basic Decision Structure here.

Fig. 2. Basic Decision Structure



Source: author's elaboration (VensimTM format)

Feedback structures of problems work through perpetual invasions in the state of equilibrium succeeded by a new equilibrium state. State of the problem is represented by “Stock”, the value of which is compared against required one (“required STOCK value” - this is a fixed converter type variable). If there is any difference (“STOCK difference” - converter variable), a decision is made affecting either “inflow” or “outflow”. Such decision decreases the difference between the present and the required stock value which takes some time - “time delay for adjustment” represents this feature of Basic Decision Structure.

All diagrams presenting Stock-and-Flow structures are composed of four different components: Stocks, Flows, Converters, and Connectors. Relationships among these variables is not ascribed to subjective choice; instead, there is a specific “grammar” of problem modeling language, narrowing choice in accordance with the following rules:

- Flows can influence Stocks
- Stocks can influence Flows or Converters
- Converters can influence Flows or other Converters

- Flows cannot influence Converters or other Flows (it is allowed, however, to convey information from Converters to other variables)
- Converters cannot directly influence Stocks
- Stocks cannot influence directly other Stocks

Modeling language and methodology

Our perception of a problem is influenced by thinking tradition, sustained by conceptual framework, and language we use. Typically, conceptual frameworks are presented as oscillating between two extreme traditions underlying the history of scientific thought. Those framework are analytic and systemic with some contrastive traits:

Tab. 1. Traits of analytic and systemic framework

Analytic Approach	Systemic Approach
First isolates, then concentrates on the elements	Unifies elements and concentrates on the interaction between elements
Studies the nature of elements	Studies the nature and effects of interactions
Emphasizes the importance of details	Emphasizes global perception
Modifies one variable at a time	Modifies groups of interconnected variables simultaneously
Independent of duration of time; changes considered reversible.	Integrates duration of time and; changes irreversibility
Experimental validation of facts within given body of a theory	Validates facts through comparison of the behavior of the model with reality
Precise and detailed models that are less useful in real-life operations	Uses models that are insufficiently rigorous to be used as bases of knowledge but are useful in decision and action; emphasize in model creation
Efficient approach when interactions are linear and weak	Efficient approach when interactions are nonlinear and strong
Leads to discipline-oriented education	Leads to multidisciplinary, problem-oriented education
Actions are programmed in detail	Actions through objectives and sensibility analysis

Source: author's elaboration

Language plays a decisive role in problem solving. We see, understand, and interpret our world through our language. As it was mentioned earlier, language influence upon our actions and problem solving consists in the natural barrier the language imposes upon: problem description and understanding cannot be any more precise than a language used for that. Unfortunately, our language has developed in a different way and is best suited to representing static values (stocks), putting on the second stage changes themselves (flows).

Thus, the main problem in Stock-and-Flow thinking is the conversion of our natural spoken/written language into modeling language, with grammatical rules and allowable relationships among different variables. Richmond (2001) explained the meanings of basic variables giving up any mathematical explanations for the sake of natural language.

Tab. 2. Natural versus Stock-and-Flow Language

Stock-and-Flow Language	Natural Language
Stock variables	Nouns representing things or status
Flow variables	Verbs representing actions or activities
Auxiliary variables	Adverbs changing volume of Flow or combining two or more variables consistently

Source: based on Richmond 2001.

Due to the nonlinear stocks' behavior, multiple flows, and feedback structures of problems, understanding and correct interpretation of real problem is a very complex task. The problem solving complexity can be mitigated by 1) the acceptance of certain rules as to understanding problem behaviors, and 2) using an appropriate methodology to structure and model problem structure.

Over the years, some regularities have been identified that consistently appear in complex problems, e. g.:

- symptoms of a problem are often separated from the actual problem and its origin by time and space;
- complex systems often behave counter to human intuition (counter-intuitive behavior);
- policy intervention in complex systems can frequently yield short-term successes but long-term failure, or short-term failure but long-term success;
- feedback problem structure often counters external policy intervention;
- it is better to structure a system to accommodate uncertain external shocks than to try to predict those external shocks;
- real-world complex systems are not in equilibrium and are continually changing.

Regarding problem solving methodology - our concept of problem solving is a sequence of three phases: structuring, modeling, and simulation. Each phase contributes to our problem knowledge and is linked with problem solving through some specific mental instruments. The last stage, computer simulation, remains beyond the scope of this text.

Problem structuring – from storytelling to problem structure

A story is the most natural way of expressing our knowledge of a problem. Purposeful use of narratives to achieve a practical outcome (problem solution) requires more analytical approach to stories. We learn about problems listening to, reading about, or telling stories. Stories can be of two modes, each providing distinctive ways of ordering experience and constructing mental models of our reality. One mode, paradigmatic, attempts to fulfill a formal system of description and explanation. It employs categorization or conceptualization and it proposes operations by which categories are established, defined, idealized, and related in order to form a system. Typical example includes using quantitative approach to problem solving where we seek information fitting the categories required by the mathematical model. The other mode, narrative, is the imaginative application of our language to that fragment of the reality which we consider “a problem”. Narrative mode includes individual interpretations of external events and it accounts and precedes our intentions as well as reflects our experience, locating them in time and space.

Story telling does not contain direct information about the problem structure. We need to approach a story in such a way that further work on the problem structure is feasible. Dynamic complexity of problems lies in variables forming the problem and relationships linking those variables and leading to pertinent feedback loops and systems. This can be done in an intuitive way (frequently resulting in a spider web diagram, difficult to understand) or supported by formal methods, e. g. Partitioning Method. Partitioning Method was proposed by Gerald Kron in 1963 for the purpose of structuring large equation systems. It allows us to group all problem variables into blocks, where a block contains variables linked with a feedback and where there are no feedback loops between blocks. As a detailed presentation of this method exceeds the scope of the paper, we present only basic operations using the problem of workers' motivation.

Suppose we consider the problem of workers' motivation that depends on their wage. Reading available information and talking to supervisors we make the inventory of possible variables constituting the problem: (1) workers' motivation, (2) workers' productivity, (3) pay per product policy, (4) workers' perception, (5) other workers' productivity, (6) motivation change (7) incentives system, and (8) other workers' ostracism.

Suppose that our story underlying the problem suggests that increasing productivity of the worker may provoke unfavorable reactions of other workers (ostracism). On the other hand, in spite of that ostracism, we may expect a positive change in others' productivity in a long run, providing that increasing productivity will modify a company incentive system forcing to pay more for individual productivity than for working time. With all these variables, ordering them may not be an easy task. Using the Partitioning Method we first elaborate the symmetric matrix where all problem variables appear as rows and columns; the diagonal of the matrix is crossed as no problem variable can directly affect itself. This must be accompanied by a discussion of the problem semantics; each problem variable must be confronted with any other variable (on one to one basis) with a view to determine whether or not one variable can directly affect another one; if it can, a cross is put in the intersection cell. Once we have completed the matrix we can start partitioning procedure. If the matrix is partitioned, all marks above the diagonal point to feedback loops existing in the problems structure. As we are at the beginning of the procedure, those marks show but only relations, without reference to their nature (see: Table 3).

Tab. 3. Example of Partitioning Method (initial and last matrix)

VARIABLES	Worker's motivation	Worker's productivity	Worker's perception	Motivation change	Incentives system	Others' ostracism	Others productivity
Worker's motivation	■			X			
Worker's productivity	X	■	X	X			X
Worker's perception			■				
Motivation change	X	X		■			
Incentives system					■		
Others' ostracism		X				■	
Others productivity					X		■
Pay per product policy					X		X

VARIABLES	Worker's perception	Incentives system	Others productivity	Pay per product Policy	Worker's motivation	Motivation change	Worker's productivity
Worker's perception	■						
Incentives system		■					
Others productivity		x	■				
Pay per product policy		x	x	■			
Worker's motivation					■	x	
Motivation change			x	x		■	
Worker's productivity					x	x	■

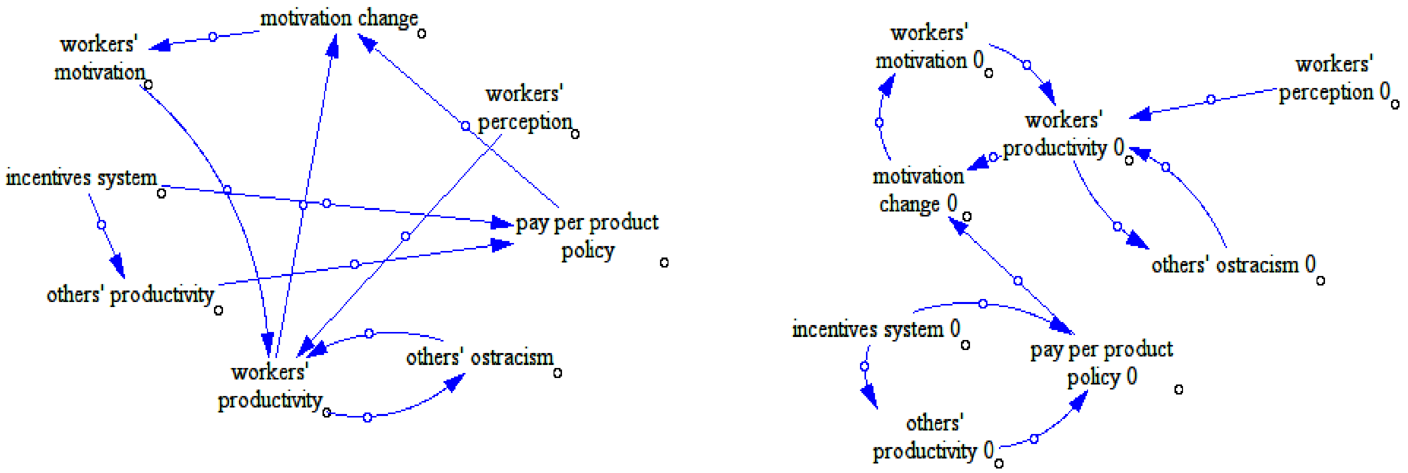
Source: author's elaboration.

In terms of causal diagramming the difference between ad hoc capturing variables and relationships among them could be as presented below:

Fig. 2. Causal diagram without (a) and with (b) Partitioning Method

(a) (b)

Note: variable name with "0" indicates replication



Source: author's elaboration.

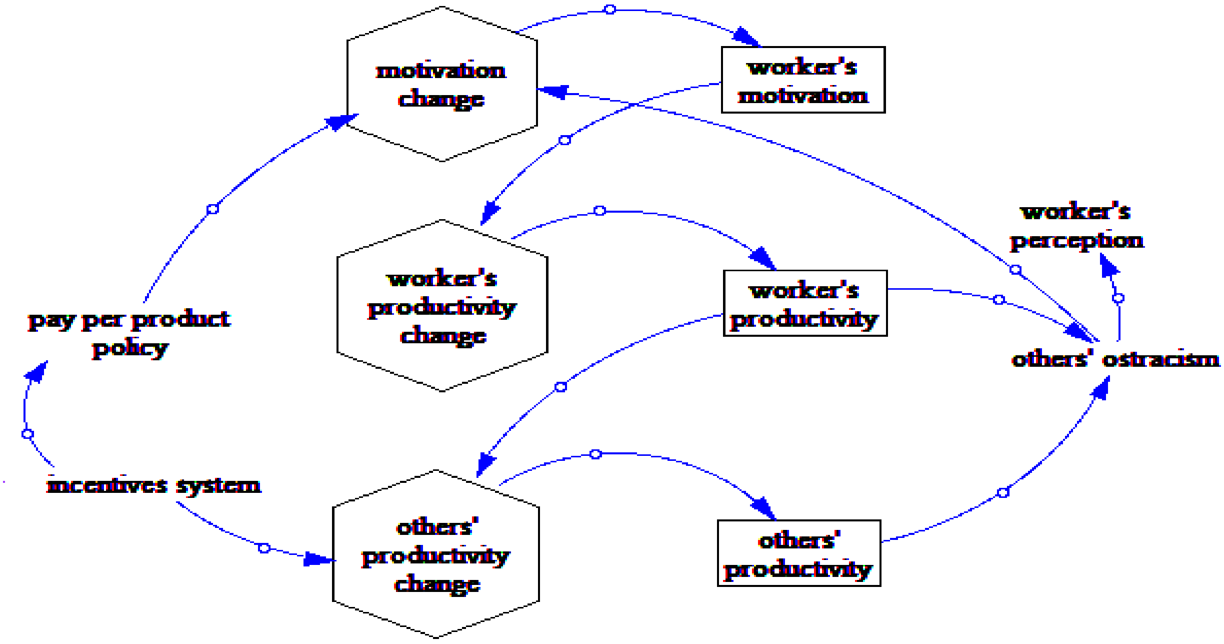
It is clear that using the Partitioning Method we receive clearer and more dynamically interpretable causal diagram. Even without further problem solving procedure (modeling and simulation) we can now make more precise insight into the dynamic character of the problem structure. First, the problem has two feedback loops that create its dynamic behavior; first – it is a positive feedback loop leading from "workers' motivation" to "workers' productivity" and then to "motivation change". As it is the positive loop, we expect strengthening or weakening behavior here. Second – there is a negative feedback loop between "workers' productivity" and "workers' ostracism"; its behavior will be counteracting each other, thus showing oscillations and seeking an equilibrium point. These two loops are the most important from the problem solution point of view; any solution should include a possibility to monitor/control their behavior.

Problem modeling

It is also very helpful in the problem modeling phase to think of the variables in terms of what type of behavior they may present (variables properties). If we analyze possible behavior of a variable over time, there are only three, mentioned earlier, distinguishable patterns: stock, state or level variables, low or rate variables, and conversion variables (converters).

Problem modeling aims at presenting perceived and presented with the causal diagram problem structure in such a way that all problem variables acquire one of the above patterns and they all are conceivable in terms of definition determining their behavior. Limited scope of this paper excludes the possibility to show all details of this operation. We confine that stage of problem modeling only to presenting previous problem structure causal diagram (after applying Partitioning Method), marking with rectangles stock variables, with diamond – flow variables, and leaving converter variables unmarked (see Fig. 3).

Fig. 3. Causal diagram with discerned variables



Source: author's elaboration.

Final remarks

Discovering problem structure and modeling variables and interrelationships existing between them has critical importance for problem solving and decision making. Some of many tools available to decision makers require preliminary distinction between accumulative variables (stock variables) and those changing stock variables (flow variables). Structuring and modeling is a necessary operation while using the System Dynamics approach to problem solving as without it is impossible to build a formal, simulative model of a problem.

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Abstrakt

Artykuł przedstawia podstawowe zasady systemowego myślenia o problemach i proponuje systemową procedurę ich rozwiązywania. Przedstawiona jest praktyczna wartość Metody Partycji w odkrywaniu systemowej (dynamicznej) struktury problemów oraz specjalne znaczenie prawidłowej interpretacji zmiennych decydujących o systemowej strukturze problemów. Tymi zmiennymi są Stock-and-Flow, absorbujące i wyzwalające sprzężeniową dynamikę zachowania problemów. Cała analiza jest osadzona w kontekście Teorii Podejmowania Dynamicznych Decyzji.